Mats Lindroos on behalf of the CERN ISOLDE team

Isotope Separation On-Line (ISOL)
Outline

• Overview of the ISOL technique
• Towards higher energies
  – ISOLDE-REX, post acceleration of radioactive ions
• Future plans
  – ISOLDE upgrade
  – EURISOL
  – Beta-beam
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ISOLDE team

Nuclear chart

- rp-process
- γ-process
- B_p = 0
- B_F = 4MeV
- B_n = 0

- stable nuclides
- ε, β⁺ - decay
- β⁻ - decay
- α - decay
- spontaneous fission
- p - decay
PS Booster

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ISOL production of exotic ions

1 GeV p

238U → spallation + 201Fr

238U → fragmentation + 11Li X

238U → fission + 143Cs Y

n p
Thick ISOL Target

- Diffusion
- Effusion
- “Chemistry”

Protons

+/- 8V
500A

+/- 9V
1000A

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Target

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1 GeV p

\( p + n \rightarrow 2^3 U \) to the “cold” converter.

UC\(_2\) target

HT-oven electrical connections

PROTONS

NEUTRONS

\( ^{144} \text{Cs} + \text{Y} \)

p+ beam-scan

(\( ^{95} \text{Kr} \) yield)

J. Lettry et al.
Ion source: laser ionization

β decay of $^{215}$Pb

On resonance

Off resonance

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Magnetic separation

- “Isobaric” separation
- Separation limited by the beams transverse size
- Cooling at low energy with RFQ cooler

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T. Giles, I. Podadera-Aliseda, A. Jokinen
Pure beams?

To get pure ISOL beams free from isobaric contamination:

• Target material
• Proton energy
• Effusion and diffusion properties
• Ion source type
• Target and ion source chemistry
• Magnetic separation
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ISOL facilities 1967
ISOL facilities 2003

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Why do we need ISOL (DE) facilities?

• **Nuclear Physics**
  – A few-body system of hadrons (neutrons and protons) with many remaining question marks
  – “Largest” system where strong and weak interaction are manifested

• **Isotopes used for the study of:**
  – Astrophysics
  – Condensed matter
  – Energy
  – Medicine
  – Neutrino physics
“And why nuclear physics? My answer is the same as that of the young student who chose nuclear physics – it is a field of basic research with fascinating fundamental problems and applications to many other areas such as medicine and material science. I believe that nuclear physics is so broad that it is well on the way to becoming the most general natural science.”

Professor Paul Kienle, 1993
Physics at ISOLDE

ISOLDE Physics Programme 2003

- **Solid state physics** 19%
- **Particle and Astrophysics** 3%
- **Biology/Medicine** 5%
- **Atomic Physics** 26%

27 Experiments

- **Weak Interaction and Nuclear Physics** 47%

- **ISOLDE Physics workshop, CERN, 15-17 December 2003**
- **Physics at SPL, CERN, 25-26 May, 2003**

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Towards higher energies

- Challenges when accelerating radioactive ions:
  - Low intensity
    - $10^5$ ions/bunch
  - Short half lives
  - Charge state
  - Beam purity

Production and ionization

- Time structure
  - Beam size

- Charge state

- Acceleration

John Adams • 10% -> 1% Mats Lindroos on behalf of the Memorial lectures

ISOLDE team
REX EBIS

For $A < 40$:
- Breeding time ($A/q < 4.5$) $< 20$ ms
- Repetition rate $50$ Hz
- Beam intensities $< 10^9$ /s
## Future plans: More Protons

**Case 3 (optimum improvements)**
- 0.9 s basic period
- Double PSB batch for CNGS (8.6×10^{13} ppp (!) in SPS)
- Linac 4 (6.4×10^{13} ppp for ISOLDE + single PSB batch for LHC & CNGS)

<table>
<thead>
<tr>
<th>LHC</th>
<th>0.9 s basic period</th>
<th>0.9 s basic period + Double PSB batch for CNGS</th>
<th>0.9 s basic period + Linac 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNGS</td>
<td>Flux × 0.95</td>
<td>Flux × 1.8</td>
<td>Flux × 1.8</td>
</tr>
<tr>
<td>ISOLDE</td>
<td>Flux × 1.6</td>
<td>Flux × 1.65</td>
<td>Flux × 3.9 (1.95×2)</td>
</tr>
<tr>
<td>Comment</td>
<td>- Shorter SPS porch</td>
<td>- Shorter SPS porch</td>
<td>- Shortest SPS &amp; LHC porches,</td>
</tr>
<tr>
<td>John Adams Memorial lectures</td>
<td>Mats Lindroos on behalf of the ISOLDE team</td>
<td>- Simple operation, margin</td>
<td>- Potential for LHC upgrade</td>
</tr>
</tbody>
</table>

R. Garoby, HIP study
Future Plans: hie isolde

Nuclear Astrophysics
Condensed Matter Physics

Nuclear Physics

Fundamental Interactions

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ISOLDE extension

planned extension 2004–2005

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Future plans: EURISOL
AIM: provide beams of electron (anti) neutrinos by decay of beta active ions.

Decay ring

$B\rho = 1500 \text{Tm}$

$B = 5 \text{T}$

$C = 7000 \text{ m}$

$L_{ss} = 2500 \text{ m}$

$^{6}\text{He}: \gamma = 150$

$^{18}\text{Ne}: \gamma = 60$
60-90 GHz « ECR Duoplasmatron » for gaseous RIB

Very high density magnetized plasma $n_e \sim 10^{14} \text{ cm}^{-3}$

2.0 – 3.0 T pulsed coils or SC coils

Very small plasma chamber $\Phi \sim 20 \text{ mm} / L \sim 5 \text{ cm}$

Target

Arbitrary distance if gas

Target

Rapid pulsed valve

UHF window or « glass » chamber (?)

Rapid pulsed valve

Optical radial coupling (if gas only)

Optical axial coupling

60-90 GHz / 10-100 KW

$10 - 200 \mu s / \lambda = 6-3 \text{ mm}$

20 - 100 $\mu s$

20 - 200 mA

$10^{12}$ to $10^{13}$ ions per bunch with high efficiency

Moriond meeting:

Pascal Sortais et al.

LPSC-Grenoble

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Overview: Decay ring

- Ejection to matched dispersion trajectory
- Asymmetric bunch merging
Asymmetric bunch merging

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S. Hancock
Asymmetric bunch merging

S. Hancock, J-L. Vallet and M. Benedikt

John Adams Memorial lectures
Mats Lindroos on behalf of the ISOLDE team
Decay losses

- Losses during acceleration are being studied:
  - Full FLUKA simulations in progress for all stages (M. Magistris, CERN-TIS)
  - Preliminary results:
    - Can be managed in low energy part
    - PS will be heavily activated
      - New fast cycling PS?
    - SPS OK!
    - Full FLUKA simulations of decay ring losses:
      - Tritium and Sodium production surrounding rock well below national limits
      - Reasonable requirements of concreting of tunnel walls to enable decommissioning of the tunnel and fixation of Tritium and Sodium

A. Jansson, M. Magistris, M. Silari

John Adams
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### Intensities

<table>
<thead>
<tr>
<th>Stage</th>
<th>(^{6}\text{He})</th>
<th>(^{18}\text{Ne}) (single target)</th>
</tr>
</thead>
<tbody>
<tr>
<td>From ECR source:</td>
<td>(2.0 \times 10^{13}) ions per second</td>
<td>(0.8 \times 10^{11}) ions per second</td>
</tr>
<tr>
<td>Storage ring:</td>
<td>(1.0 \times 10^{12}) ions per bunch</td>
<td>(4.1 \times 10^{10}) ions per bunch</td>
</tr>
<tr>
<td>Fast cycling synch:</td>
<td>(1.0 \times 10^{12}) ion per bunch</td>
<td>(4.1 \times 10^{10}) ion per bunch</td>
</tr>
<tr>
<td>PS after acceleration:</td>
<td>(1.0 \times 10^{13}) ions per batch</td>
<td>(5.2 \times 10^{11}) ions per batch</td>
</tr>
<tr>
<td>SPS after acceleration:</td>
<td>(0.9 \times 10^{13}) ions per batch</td>
<td>(4.9 \times 10^{11}) ions per batch</td>
</tr>
<tr>
<td>Decay ring:</td>
<td>(2.0 \times 10^{14}) ions in four 10 ns long bunch</td>
<td>(9.1 \times 10^{12}) ions in four 10 ns long bunch</td>
</tr>
</tbody>
</table>

Only β-decay losses accounted for, add efficiency losses (50%)
Conclusions

- The ISOL technique
  - Powerful technique for the production of radioactive nuclei
- Nuclear physics and its applications:
  - Have a great past
  - and an exciting future at new large scale facilities
- Thank you for your attention!